U.S. Army Research, Development and Engineering Command

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Level Dependent Hearing Protector Model

For use with the

Auditory Hazard Assessment Algorithm for Humans (AHAAH)

Paul D. Fedele
Joel T. Kalb
U.S. Army Research Laboratory
Human Research & Engineering Directorate

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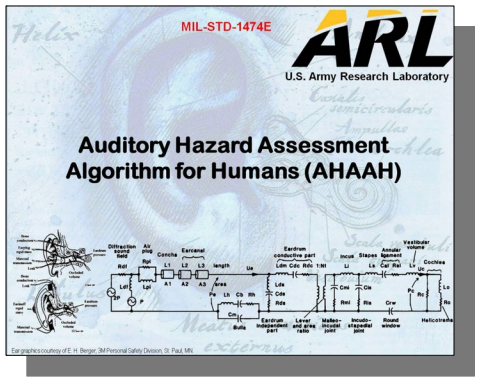
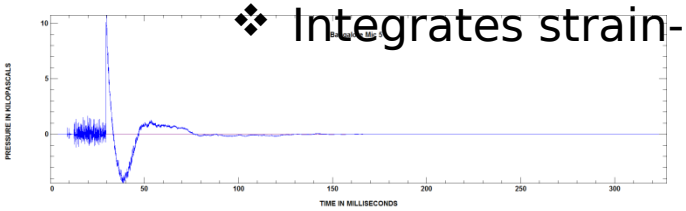
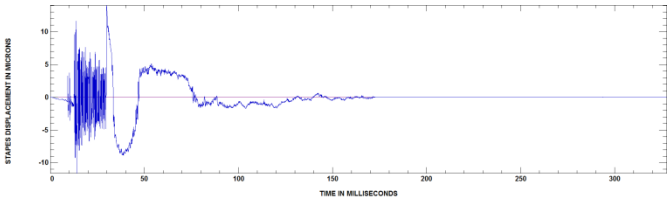
What is the AHAAH



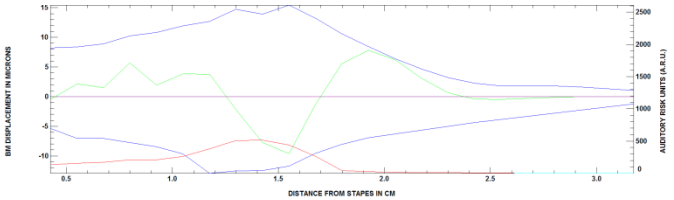
- Electro-acoustic model that calculates human hearing damage
- Applies to impulse noises: explosions, gunfire, airbag deployment
- Uses detailed pressure waveform measurements
- Physically calculates dynamic level dependent responses
- Integrates strain-induced damage in the inner ear



- Detailed pressure waveform
- Several optional locations



- Time-dependent auditory reflex
- Stapes displacement
- Dynamic level dependent analysis



- Basilar membrane displacement
- Integrated strain damage
- Calibrated auditory risk units (ARU)

500 ARU = 5th percentile hearing loss

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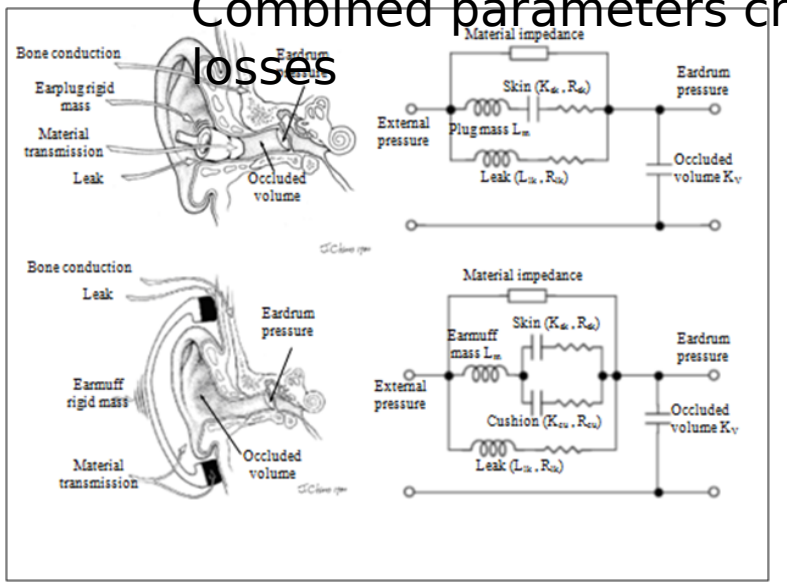
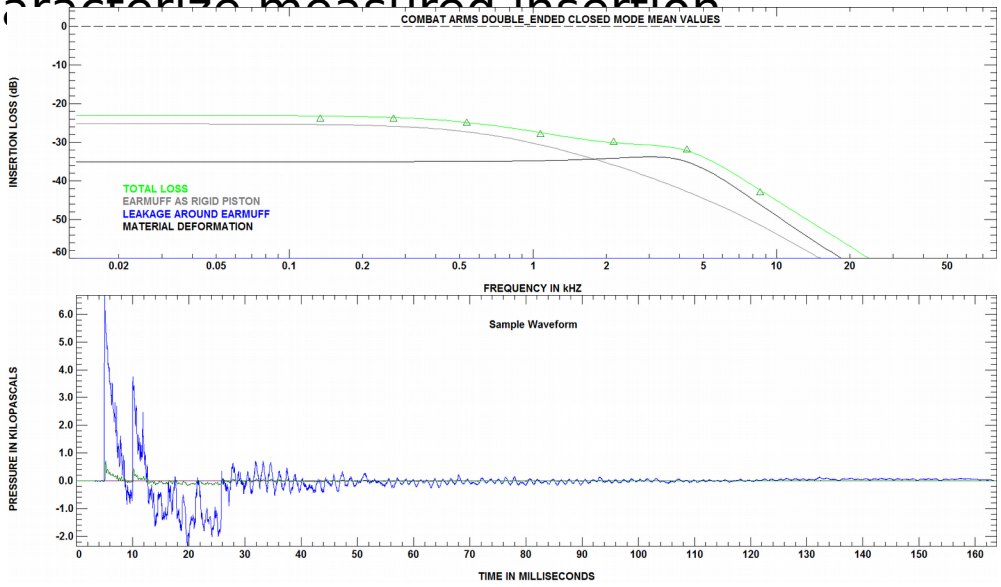
Non-Level Dependent Hearing Protectors (HP)

Electro-acoustic linear hearing protection (HP) model
Three independent *modes* of pressure wave transmission

- HP material deformation piston (high frequency)
- Whole HP rigid inertial piston (intermediate frequency)
- Leak air piston (low frequency)

Combined parameters characterize measured insertion losses





Model fits attenuation measurements and determines waveform under the HP

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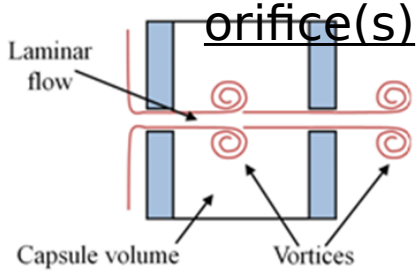
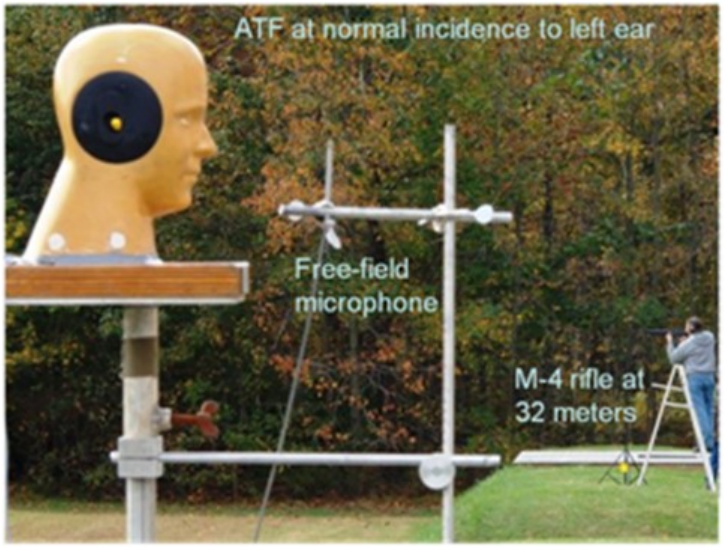
Level Dependent Hearing Protectors

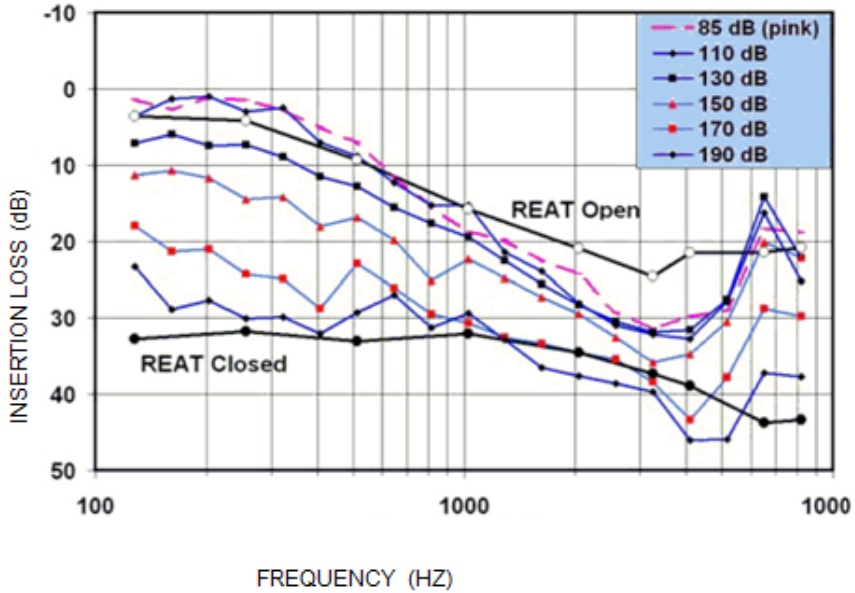
Pressure-variable resistance of flow through orifice(s)



- Higher driving pressures
- More vortex shedding
- Increased energy loss
- Increased flow resistance



Measure insertion loss with acoustic test fixture at varying ranges from M-4 rifle fire



Insertion loss shows increased attenuation with increased waveform peak pressure

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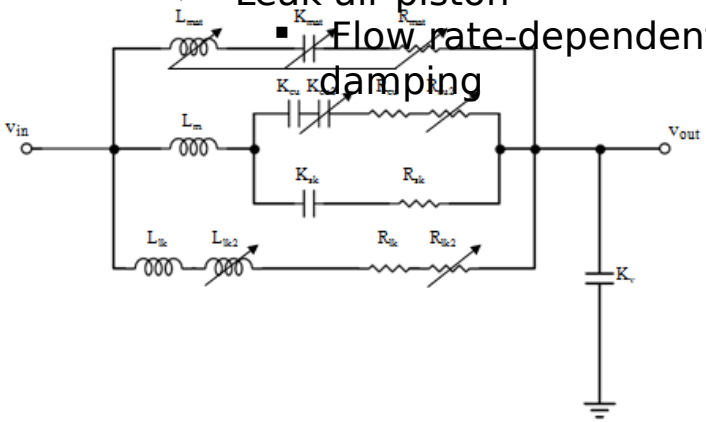
Level Dependent Hearing

- Add level dependent elements to electro-acoustic linear HP model
- Same three independent *modes* of pressure wave transmission
  - HP material deformation piston
    - Driving pressure-dependent inertia and resistance
  - Whole HP as rigid inertial piston
    - Displacement-dependent hardening spring compliance with increased resistance to offset resonance
  - Leak air piston
    - Flow rate-dependent r… t over damping



$$K_{m1} = K_m + K_{m2} = K_m + K_m \frac{q_4^2}{q_0^2} = K_m \left(1 + \frac{q_4^2}{q_0^2}\right)$$

$$R_{m1} = R_m + R_{m2} = R_m + R_m \frac{q_4^2}{q_0^2} = R_m \left(1 + \frac{q_4^2}{q_0^2}\right)$$

$$R_{lk1} = R_{lk} + R_{lk2} = R_{lk} + R_{lk} \frac{i_2^2}{i_0^2} = R_{lk} \left(1 + \frac{i_2^2}{i_0^2}\right) = R_{lk} \left(1 + \left(\frac{1}{i_0^2}\right) i_2^2\right)$$

$$L_{lk1} = L_{lk} + L_{lk2} = L_{lk} + L_{lk} \frac{i_2^2}{i_0^2} = L_{lk} \left(1 + \frac{i_2^2}{i_0^2}\right) = L_{lk} \left(1 + \left(\frac{1}{i_0^2}\right) i_2^2\right)$$

  - Compliance (spring constant) and resistance (damping):
    - Increase with squared displacement (accumulated charge, q)
  - Resistance (damping) and inertia (inductance):
    - Increases with squared flow rate (current, i)

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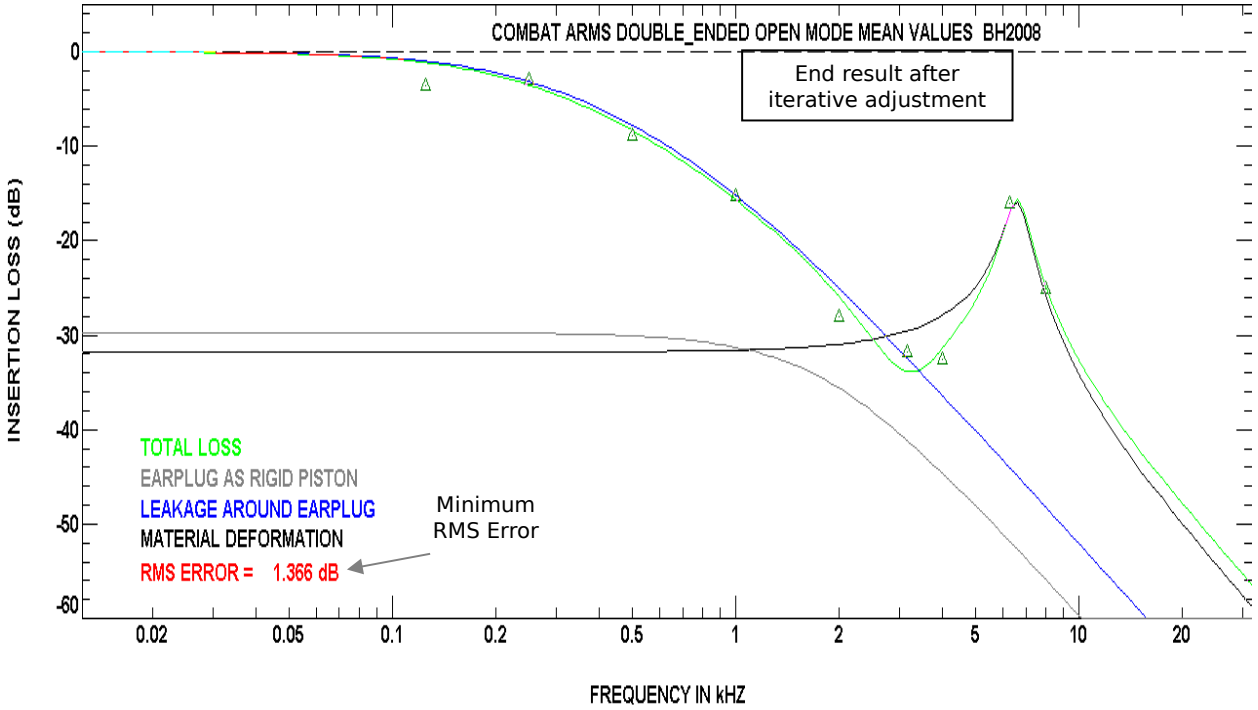
Level Dependent Hearing

Adjust piston parameters to fit low-peak-pressure REAT Data



Notice:

- Leak dominates attenuation at low-frequencies
- Earplug as rigid inertial piston remains fixed
- Material deformation piston may change oscillatory modes and result is resonance ~7KHz.
- Three piston model fits low peak pressure (REAT) measurements.

Earplug insertion loss is measured by the difference in hearing threshold of people with and without HPs

Real Ear Attenuation at Threshold (REAT) involves low-level sounds: ~ 30 dB or less.

Model successfully fits insertion losses measured in low-pressure REAT evaluations

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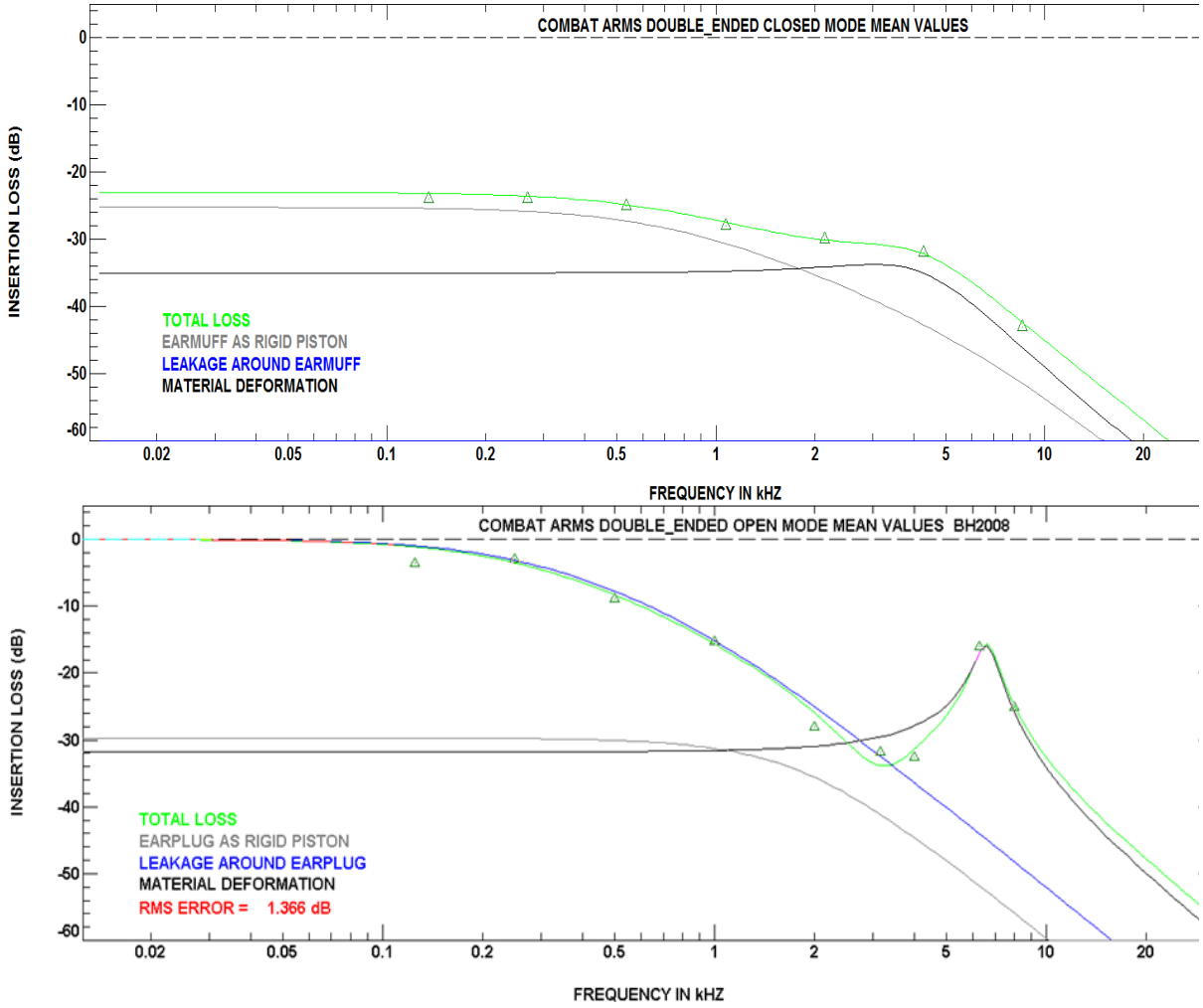
Level Dependent Hearing

Notice:

- Opening leak dominates attenuation at low-frequencies
- Material deformation piston changes and creates oscillatory resonance ~7KHz.
- Three piston model successfully fits low peak pressure (REAT) measurements.



Model fits REAT data, but does it fit high-pressure impulse insertion loss?

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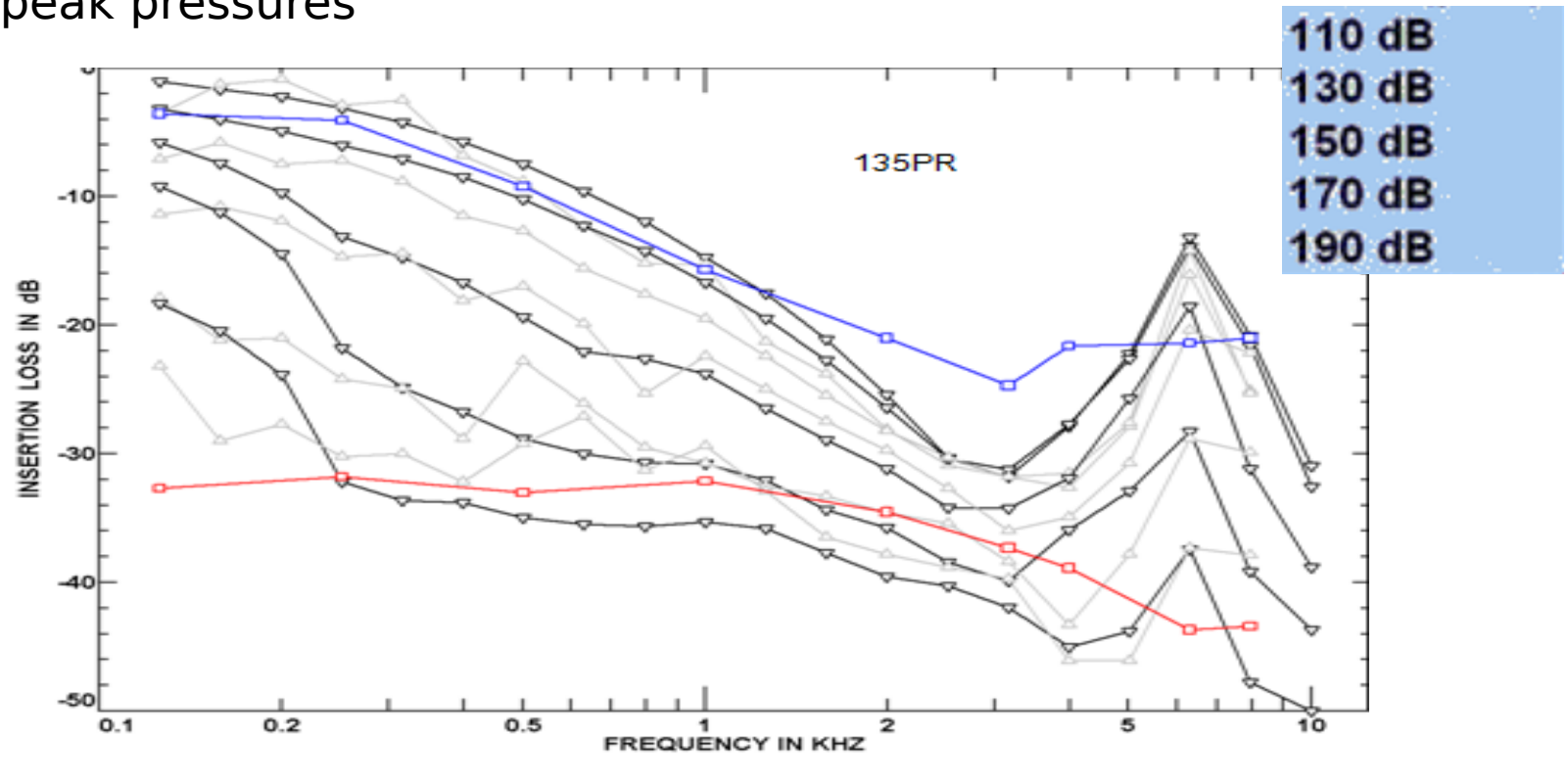
Level Dependent Hearing

Compare insertion loss (IL) from LDHP model with insertion loss measured using the auditory test fixture and varying peak pressures



Blue line: REAT data open plug; Red line: REAT data closed plug; Light lines: measured IL; Dark lines: modeled IL

The LDHP model fits the IL measurements for impulse peak pressures of does it fit high-amplitude impulse insertion loss? What about the resonance?

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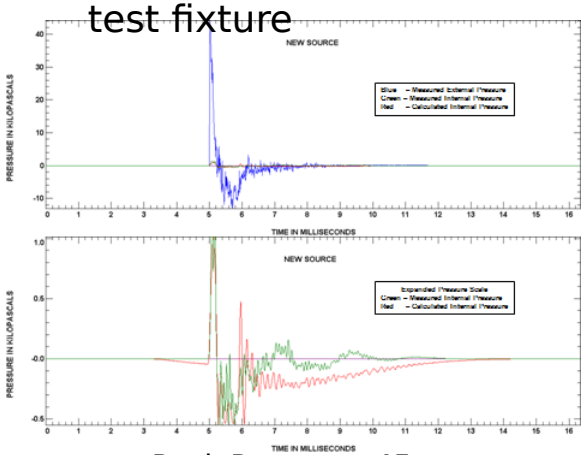
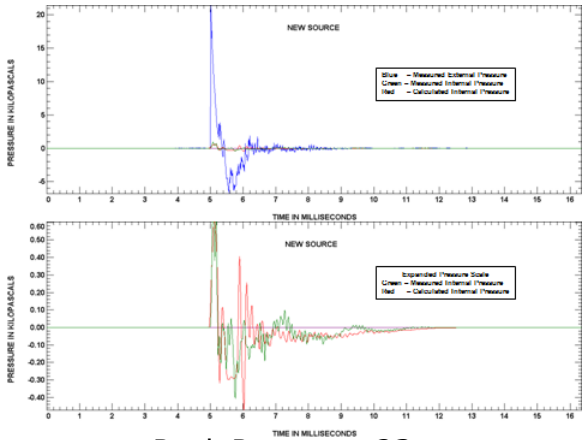
Level Dependent Hearing

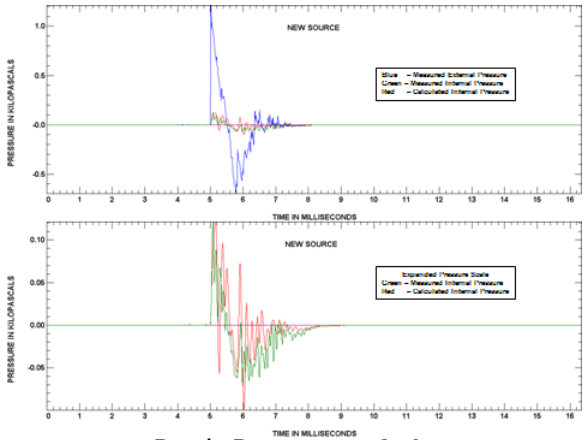
Compare calculated and measured pressure waves under hearing protectors in auditory test fixture



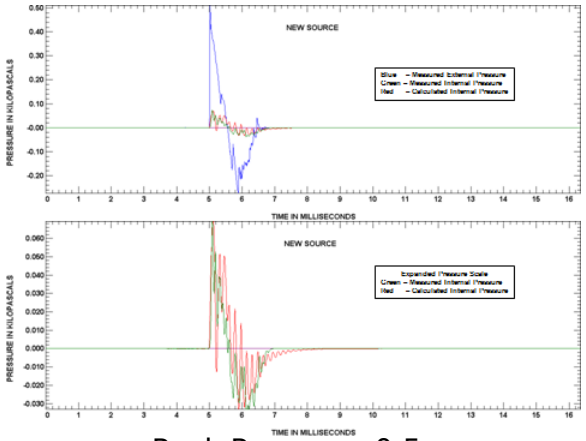
Peak Pressure: 45 KPa



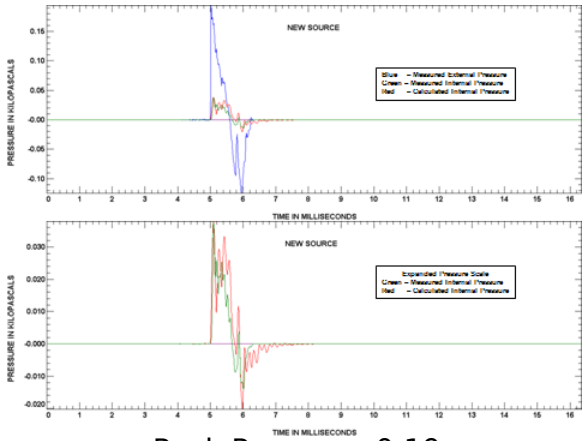
Peak Pressure: 23 KPa



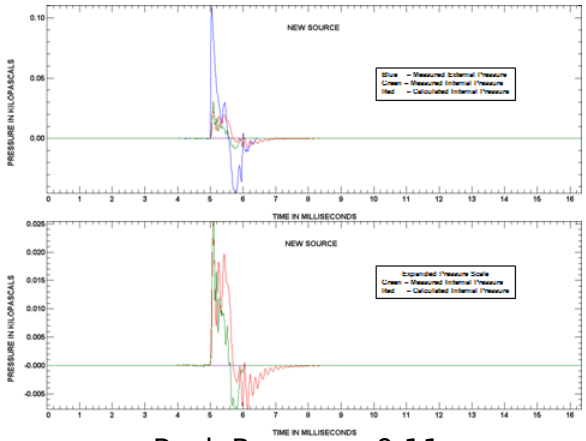
Peak Pressure: 1.4 KPa



Peak Pressure: 0.5 KPa



Peak Pressure: 0.19 KPa



Peak Pressure: 0.11 KPa

LDHP performance is characterized sufficiently to accurately assess hearing risk for LDHPs over pressure levels

Level Dependent HP Model

- LDHP model describes observations of measured LDHP performance
- AHAAH and the LDHP model dynamically apply level dependent behavior in HP and middle ear transmission
- AHAAH with included HP models (including LDHP models) offers the only hearing hazard evaluation process capable of accurately evaluating hazards posed by waveforms that do not necessarily conform to a standard time-dependent form

- Ongoing work is needed to:
  - Gather more measured LDHP IL performance
  - Fit LDHP model parameters to more LDHPs
  - Expand the HP and LDHP content in AHAAH

Joel T. Kalb, Ph.D.
Senior Research Physicist
ARMY RESEARCH LABORATORY
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Human Research & Engineering Directorate
ATTN: RDRL-HRS-D
520 Mulberry Point Road
Aberdeen Proving Ground, MD
21005-5425
Office: 410.278-5977
DSN: 298-59
Fax: 410.278-358
joel.t.kalb.civ@mail.mi

Thank You!

Paul D. Fedele, Ph.D.
Senior Research Physicist
ARMY RESEARCH LABORATORY
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Human Research & Engineering Directorate
ATTN: RDRL-HRS-D
520 Mulberry Point Road
Aberdeen Proving Ground, MD
21005-5425
Office: 410.278-5984
DSN: 298-5984
Fax: 410.278-3587
paul.d.fedele.civ@mail.mil

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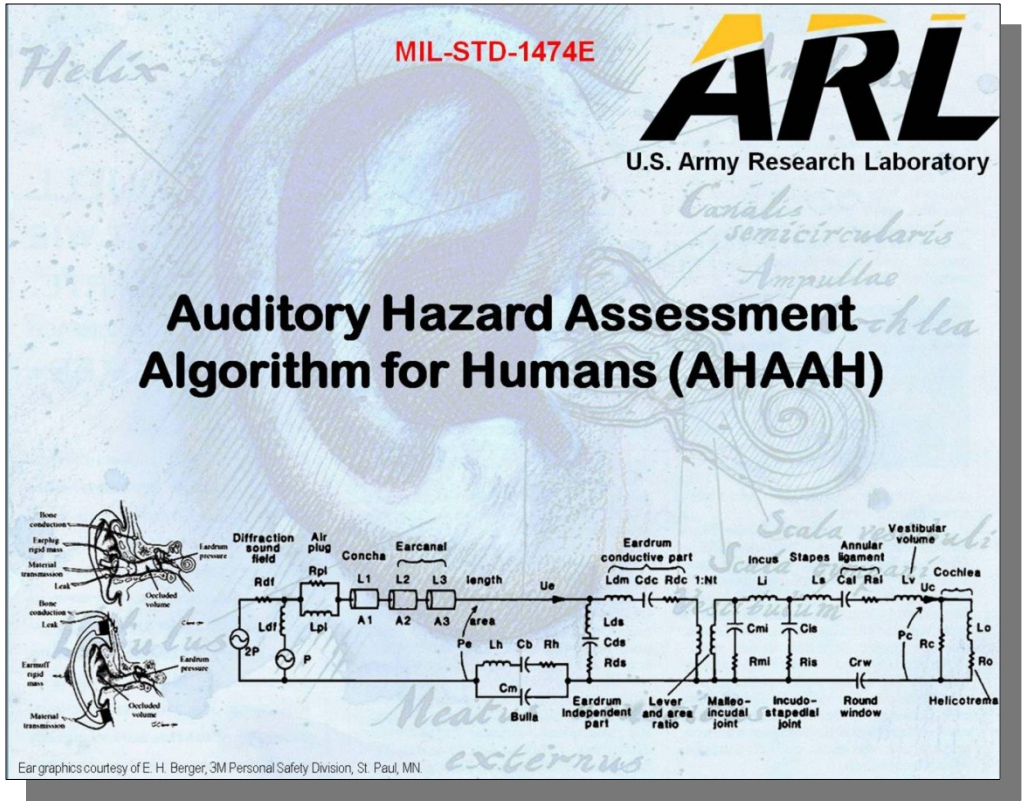
Auditory Hazard Assessment Algorithm for Humans

The most advanced of the noise hazard metrics is the theoretically-based Auditory Hazard Assessment Algorithm for Humans (AHAAH).

- Takes into account the whole signal transmission from the free sound field to the cochlear structures
- Based on the calculated time-history of the displacement of the basilar membrane (mechanical stress, elongation, number of cycles, etc.)
- Does not estimate percentage of the population that would sustain a permanent threshold shift based on impulsive sound measurements under a variety of exposure conditions
- Accounts for impulse noise measurements in the free sound field, at the ear canal entrance, and at the tympanic membrane



Auditory Hazard Assessment Algorithm for Humans

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Auditory Hazard Assessment Algorithm for Humans (AHAAH)

http://www.arl.army.mil/ahaah

Modern weapons and a broad spectrum of industrial machinery produce intense acoustic impulses that can make them unsafe, limit their use, or restrict their design. Recent studies indicate that all current noise exposure standards and design guidelines for impulse generating weapons are seriously in error. To overcome these limitations, ARL's Human Research and Engineering Directorate (HRED) developed a mathematical model of the human auditory system that predicts the hazard from any free-field pressure and provides a visual display of the damage process as it is occurring. The model is a powerful design tool that shows the specific parts of the waveform that need to be addressed in machinery and weapon design. This unique model is the only method of assessing noise hazard for the entire range of impulses that are relevant to the Army. The model has the potential to serve as an international design standard for weapons and to provide damage or risk criteria for intense impulses of industrial origin.

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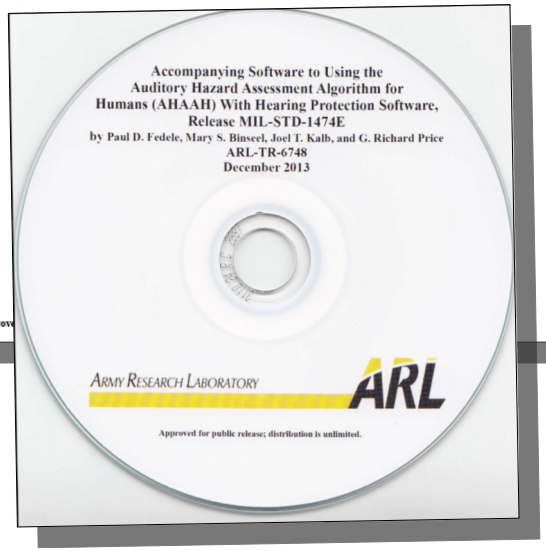
Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) With Hearing Protection Software, Release MIL-STD-1474E

by Paul D. Fedele, Mary S. Binseel, Joel T. Kalb, and G. Richard Price

ARL-TR-6748 **December 201**


Accompanying Software to Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) With Hearing Protection Software, Release MIL-STD-1474E
by Paul D. Fedele, Mary S. Binseel, Joel T. Kalb, and G. Richard Price
ARL-TR-6748
December 2013
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Validation of the auditory hazard assessment algorithm for the human with impulse noise data

G. Richard Price[a)]
Auditory Hazard Analysis, P.O.B. 368, Charlestown, Maryland 21914

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Predicting auditory hazard from intense acoustic impulses, such as weapons fire or airbags, has been an intractable problem. The U.S. Army developed a theoretically based mathematical model of the ear designed to predict such hazards [the Auditory Hazard Assessment Algorithm for the Human (AHAAH)]. To validate it as a predictor of hazard, data from the literature (wave forms and changes in hearing sensitivity) were processed with the model in order to predict the onset of unacceptable threshold shift (25 dB or more) in the 95th percentile human ear. For comparison, alternate standards MIL-STD-1747D and A-weighted energy were also used to compute hazards for the same data. The primary dataset was that of the US Army's "Albuquerque studies" (53 different cases) and other impulses from the literature (19 additional predictions). The AHAAH model predicted correctly in over 95% of the cases, the MIL-STD-1474D was correct in 42% of the cases, and A-weighted energy was correct in 25% of the cases. Errors for all methods tended to be in the direction of overprediction of hazard. In addition to greatly increased accuracy, the AHAAH model also has the advantage of being theoretically based and including novel diagnostic features.
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